

MANUAL OF SAMPLING AND STATISTICAL METHODS FOR FISHERIES BIOLOGY

PART 1. SAMPLING METHODS

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Section 4. Sampling the population in the sea



CONTENTS

SECTION 4. Sampling the population in the sea	1
4.1 General problems	1
4.2 Surveys with a research vessel	3
4.3 Commercial catches as samples of the population	7
4.3.1 Index of abundance.	7
Example 4.3.1.1	9
Example 4.3.1.2	11
Example 4.3.1.3	12
4.4 Composition of the stock	12
Example 4.4.0.1	14
4.4.1 Fishing by more than one fleet.	16
Example 4.4.1.1	17
Example 4.4.1.2	18
4.4.2 Age-length keys	19
Example 4.4.2.1	19

SECTION 4. SAMPLING THE POPULATION IN THE SEA

4.1 General problems

The previous section is concerned with the sampling of a clearly defined and observable group — the fish caught or landed by the fishing fleet. The sampling problem is relatively straightforward, and theoretically it is possible to achieve complete accuracy by sampling the complete catch — and indeed this can sometimes actually be done, for instance for whales, where the length of each one caught is recorded. The research worker is however particularly interested in the natural population from which the catch comes — though it must not be overlooked that even when the catch is far from representative of the natural population information on the age and length composition, etc. of the catch is of great importance as these are the fish that are actually being removed from the stock. For instance, the age composition of the catch may be different from that of the stock. Direct estimation of, say, mortality from catch data is therefore difficult, but the difference in age composition between catch and stock means that fishing mortality varies with age, and therefore detailed knowledge of how many fish of each age are caught is important. The estimation of what is in fact the population of fish or other organisms in the sea is of course a major research task, and much of it is outside the scope of this manual, but there are many possible applications of straightforward statistical and sampling techniques. Many of these applications are relevant not only to the estimation of stocks of commercial fish but also to other fishery and oceanographic problems, e.g. plankton surveys. The first stage in the sampling program, either in planning the work of a special research vessel, or in analyzing catches of the commercial fishermen, concerns the type of gear — and for many, if not nearly all, fishery workers the most important single class of gear used in sampling the natural population is the fishing gear of the ordinary fisherman.

All, or nearly all marine sampling instruments are highly biased, and sample representatively only a small proportion of the true population. For instance, a fine meshed plankton net will allow the larger and more active planktonic animals progressively to escape, while a coarser meshed net will seriously underestimate the quantities of the small larval plankton. Again, with a trawl, the small fish can escape through the meshes, while some of the most active swimmers may escape from the

path of the trawl completely. The gear used has therefore to be carefully chosen in relation to the particular organism being studied, with the corollary that estimates for other organisms will almost certainly be biased.

A distinction may be drawn between gear which can estimate numbers on an absolute scale, and those which can give only relative numbers, or indexes of abundance. Thus catches of fish eggs with a Hensen net can, with suitable precautions, be expressed as numbers below a square meter of surface, or numbers per cubic meter. Catches with a trawl cannot usually be expressed more precisely than numbers per haul of standard duration; if this catch per unit effort is twice that at some other time, or in some other place, then it may be presumed that the fish are twice as abundant, but the absolute scale of numbers, or numbers per unit area, is not known. The sampling power of the gear — trawl, seine, etc. — that is, the amount taken on a given density of fish, is not likely to be the same for each species of fish; apart from the more obvious forms of selection, determined to a large extent from the geometry of the gear — for example, escape of small fish through the meshes of a trawl or seine, or selection by a gill net, both of which are determined by the relative circumferences of fish and mesh — the type of fish caught is to a large extent governed by details of the exact rigging of the gear, and behavior of the fish.

Selection by size of fish but not selection due to differences in behavior may be reduced by using a range of mesh sizes. For instance a fleet of gill nets of suitably graded mesh sizes might be used in two locations in an African lake. In the first 100 predatory *Hydrocyon* and 50 herbivorous *Tilapia* were caught; at the second, in the same fishing time, 50 *Hydrocyon* and 150 *Tilapia* were caught. These data, with due reservation concerning random sampling variations, show that the density of *Hydrocyon* in the first area is twice that in the second, but that the density of *Tilapia* is three times as high in the second area as in the first. However, because the active, predatory *Hydrocyon* is much more likely to encounter a gill net it is not possible, without first having some information from which the greater vulnerability can be expressed in quantitative terms, to compare the densities of the two different species.

Similar sorts of selection — that is, difference in catches on a given density of fish — can occur with a single species of fish at different times. Thus there may be definite seasonal changes in catches not apparently connected with real changes in total stock density, or, on a smaller time scale, differences between catches during day and night. Such differences should not introduce errors into the sampling system if it is properly designed. Thus if much bigger catches are taken by day than by night, then the proportion of fishing by day should not be different in different areas or in different years — otherwise an area might appear to have the highest density of fish merely because relatively more fishing by day was done in that area. The actual proportion does not matter — it may be both comfortable and convenient for a research vessel to do all its fishing in daytime (proportion of day fishing always = 1) and none at

night, while fishing by commercial vessels may be continuous in all areas (proportion of day fishing = 0.5). Seasonal changes may be eliminated in the same way. Again the seasonal distribution of fishing should be the same in different years, or in different areas; for research sampling this may be rather more difficult because of other possible work to be done, while the seasonal pattern of commercial fishing may change with changes in the abundance of fish, market conditions, etc. For instance, the decline in a stock of fish previously fished throughout the year may mean that it is only profitable to fish it at the season when catches are highest. If this change in the season of fishing were not detected and taken into account, the decline in the stocks, as measured by the catch of commercial fishermen, would be markedly underestimated.

4.2 Surveys with a research vessel

Once the most suitable gear has been chosen, the chief difficulty in sampling the natural population lies in the generally very patchy distribution. Very big differences in samples occur with virtually all the organisms a fishery worker is likely to wish to sample (fish, plankton, benthos, etc.). These differences include marked and consistent ones between large areas, or between seasons, and apparently random variations at one time and position. Thus catches of plaice are, on the average, much higher in the southern and shallower part of the North Sea than in the north, and within each region there are well-known grounds giving good fishing. However, repeated trawl hauls on the same ground under apparently the same conditions may give catches differing by a factor of 2 or more. This rather large variance and also the usually high cost of a single observation mean that it is particularly important to ensure that the sampling system used is as efficient as possible — i.e. gives the smallest variance for a given cost. As usual this is likely to be achieved firstly by using some suitable stratification — dividing the area in subareas within which conditions are more nearly uniform — and secondly by taking as many samples as possible, if necessary at the cost of reducing the size of sample.

The first step in stratification will be division into broad geographical regions, within which more detailed subdivision is possible. For bottom living animals (including demersal fish) depth is a very important factor, and stratification by depth zone is very likely to give improved accuracy. Other stratifications may be determined before starting the survey from other elements in the environment — current systems, or during the survey on the basis of the catches being made. For instance, much of the efficiency possible in stratified sampling will only be achieved if the sampling effort is properly divided between strata, i.e. if most samples are taken where the variance is greatest — normally where the abundance is great-

est. Thus the early samples taken during a survey may be used to determine a rough pattern of abundance and distribution of some organism, from which the areas in which more intensive sampling is desirable can be determined. In its simplest form, this merely involves stopping a line of stations as soon as one, or perhaps two, blank hauls have been made, and otherwise maintaining the same pattern of lines of stations within the survey area. The efficiency will be much further increased by varying the intensity of sampling — for instance, having lines of stations perhaps 60 kilometers apart at the fringes of the distribution, 30 kilometers nearer the center, and 15 kilometers or less where the abundance is highest.

The similarities between surveys by a research vessel and any other type of sampling scheme are often concealed by the method of analysis using contour lines at certain levels of abundance. Drawing such contours has very definite value as a descriptive procedure for the pattern of distribution of any organism, and one which may be compared with other distributions — of hydrographic factors, food, etc. The contour charts may also be used to estimate the total abundance, by calculating the area between each pair of contour lines, and multiplying this by the value midway between the contour lines.

This procedure is not very different from normal stratified sampling, but to use it to obtain a precise estimate requires that the contour lines be drawn with some care and the areas calculated quite precisely, both of which can be time consuming, and which tend to attach a greater degree of precision to the exact position of a contour line than is normally justified. An alternative procedure, which is more clearly the same as methods of stratified sampling described in earlier sections, is to divide the region into subdivisions of known area (calculation of the area may be made less laborious if at least the majority of the dividing lines run north-south or east-west), estimate the density in each subdivision as the mean of the observations (e.g. catch per haul) made in that subdivision, calculate the abundance in each division as the product of area $\times$ density, and hence estimate the total abundance as the sum of the abundances in each sub-area. A special form of this procedure is to conduct a survey with a uniform grid of stations, say 15 kilometers apart. Then each station can be considered as a sample from the 15-kilometer square of which it is a center, and the estimate of the mean density is the mean of the densities at the individual stations. For any one organism, unless very uniformly distributed, this pattern of sampling is inefficient, possibly greatly so, because too big a proportion of the sampling effort is made in areas where the density is low. It is most likely to be useful when making a whole range of observations (hydrographic, phytoplankton, zooplankton), each with a different distribution. The difference in the estimates obtained from contouring and from the direct means of observations (stratified as necessary) is probably not much, as can be checked by using both methods on the same set of data. As the second method makes use of the full information available, and is less likely to contain computational mistakes, it is probably rather more precise than the

contouring method. In such survey work it is therefore likely to be best to use contours to give a general description of the situation, and the straightforward stratified sampling to give the quantitative estimates.

As usual, avoidance of bias is a major sampling problem. Bias introduced by the type of gear used has already been discussed, and is essentially a problem of design of fishing gear, etc., and outside the scope of this manual. Bias can also be introduced through the choice of sampling position. Strictly, of course, unbiased sampling is best achieved by truly random sampling. The practical difficulties in using a set of sampling stations each chosen randomly and independently are very great, and the time spent moving from station to station would be greatly increased. A systematic grid, with lines of stations at regular intervals, is the standard practice, and only the precise position of the origin of the grid need be taken at random. Further, because the lines of latitude and longitude are, so far as any small area is concerned, artificial concepts, they may be considered as random relative to the natural population, and thus form a convenient basic grid for the lines of samples. Some care should be taken when there are definite trends running east and west (or north and south). Here, and anywhere where there is a marked trend, detailed stratification is particularly useful. Suppose there is a coastline running north and south and say the numbers of fish caught on hook and line decrease with increasing distance from the coast. Then the whole area should be divided into strips parallel to the coast, and an appropriate sampling pattern would be lines running east and west, perpendicular to the coast, with each line having one or more stations in each strip.

The sampling pattern particularly to be avoided is one in which the sampling positions, within the finest stratification used, have been chosen with reference to the characteristics being sampled. For instance, it is tempting, when fishing to determine the relative abundance and other characteristics of a fish stock, to do so at points where it is known that good catches, and therefore large samples (e.g. for racial analysis), are probable. So long as the habits and distribution of the fish are unaltered, the data will give reliable estimates of the relative abundance of the fish. However, if the distribution of the fish changes, without altering their total abundance, the catches will decrease, apparently as a result of a decrease in the stock abundance. This does not mean that, for example, experimental trawling should not be made on good trawling ground, in the sense of grounds where the bottom is smooth and sampling with a trawl can be done without undue risk of damage to the gear; but a ground should not be chosen merely because it is a good ground in the sense of having plenty of fish. It must be emphasized that this danger only refers to the choice of sampling position within the finest stratification. Overall sampling should be concentrated where the abundance is greatest; that is the stratifications with the greatest abundance will have the most intensive sampling, though within each stratification the distribution of sampling will be random, or nearly random — e.g. on a grid.

The intensity of sampling — how far apart to have the stations — is mainly determined by three factors: the variance between estimates from different stations, the time taken to move between stations, and the time spent sampling on any one station. The problem is therefore analogous to the two-stage sampling discussed previously, and as before, the exact solution can only be determined from data of the particular problem concerned. Increased variance between samples requires more samples, increased time on one sample implies fewer samples. The similarity with previous two-stage sampling problems is even closer when there is a possibility of varying the size of sample at any one station, e.g. by taking more than one haul with a plankton net, or using two- or three-hour hauls with a trawl, rather than a short, perhaps half-hour tow. Factors which have then to be considered are the variance between different samples at the same station (for long trawl hauls the difference between the catch in a one-hour haul and the extra fish caught in a two-hour haul), and the time spent at a station, but not actually sampling — e.g. shooting the trawl. If the within-station variance or the nonsampling time on station is small, then it is best to take a small sample (a single plankton net haul, or a short trawl haul). Conversely, if successive hauls at the same station differ almost as much as hauls five or ten miles apart, or if it takes a long time to stop the ship and prepare the gear for sampling, or to shoot and haul the trawl, then a large sample (several net hauls, or a two-hour trawl haul) is likely to be best. On the whole small samples are likely to be best to use unless there is information to suggest otherwise — that is, where the sampling gear takes discrete samples (vertically hauled plankton nets, bottom samplers, etc.) it is usually best to take one sample at each station. For ordinary trawls the best is probably a duration of perhaps half an hour, longer in deep water when hauling takes longer, and for other gears (e.g. Agassiz trawls, towed plankton nets) a short haul at each station.

The natural pattern of sampling is on a grid of stations, spaced at regular intervals along lines at regular intervals. There is no overriding reason why these intervals should be the same — the stations could be 8 kilometers apart, and the lines 15 kilometers apart, and this difference may be used to improve the sampling efficiency. Much of the time spent by a research vessel during a survey is spent steaming between stations. This time is not increased greatly by adding more stations in a line, but is at once increased if an extra line of stations is added. The greatest number of samples in a given time at sea is therefore obtained by having stations close together along lines which are far apart. In any very extreme form this sampling pattern would generally be inefficient in terms of the information obtained from a given number of stations, because there would not be much difference between successive stations in the same line, but big differences between lines, with the gap between the lines being poorly sampled. A not very infrequent exception is the situation where the changes in one direction (say north-south) are greater than those in the direction at right angles (east-west). If the lines

run in the direction of greatest change then the differences between successive stations close together in the same line may be the same as differences between adjacent lines which are some distance apart.

So far only a single survey has been considered. Usually a research worker is concerned with changes in the abundance and distribution of an organism in time as well as in space. The question therefore arises whether to use the available resources, not only of ship's time, but also for subsequent analysis of the material collected, to obtain a small number of detailed surveys, say at monthly intervals, or rather more, but less detailed surveys, say at weekly intervals. Statistical considerations alone are not sufficient to answer this question, but they would suggest that the larger numbers of surveys are better, provided that each individual survey is not too scrappy.

4.3 Commercial catches as samples of the population

Information on commercial catches is of great importance in itself in any study of exploited fish stock, because this is what is being taken from the stock. It is also most important in being one of the best sources of data on the fish population itself. In a fishery of any appreciable magnitude the number of operations made by commercial fishermen (e.g. number of nets used), and the numbers of fish caught, will be vastly greater than can be achieved by a research vessel. If there is a reasonable system of collecting statistical data on commercial catches and fishing effort, each of these numerous operations can be used as a sample of the exploited population. The resultant estimates from such a large number of samples will have small variance. Unfortunately the chance of bias is correspondingly large in estimates of both abundance and composition of the stock. This bias can, however, be in many situations reduced or even eliminated.

4.3.1 INDEXES OF ABUNDANCE

A fisherman will always fish where he thinks fish will be abundant. His catch per unit effort will therefore be higher than that obtained by, say, a research vessel fishing randomly. This does not affect the value of his catch per unit effort as an index of the abundance of the fish stock — it merely alters the value of the coefficient of proportionality relating catch per unit to stock abundance. Mathematically, denoting this coefficient by q , we can say that q (research vessel) is less than q (commercial fisherman), but both can be equally valid. Bias arises when q varies. Such variations can be divided into:

- (a) short-term fluctuations in time, of more or less regular periods — day and night — or seasonal changes;
- (b) long-term trends;

- (c) irregular changes in time;
- (d) changes correlated with fish abundance;
- (e) changes correlated with the amount of fishing.

The causes of these changes can themselves be divided into fairly distinct groups:

- (i) changes in the vessel and gear — that is, in the fishing power of the fishing unit;
- (ii) changes in the distribution of fish and fishing.

For example, improvements in the gear will produce a general increase in the catches on a given density of fish — i.e. a long-term trend in q ; so also will improved navigational or fish-finding devices which enable the fishermen to concentrate better on the high densities of fish.

The first classification is the most relevant so far as the ultimate use of catch per unit data is concerned. If, for instance, the effect of changes in the amount of fishing on the stock is being studied, then any undetected type (e) or possibly type (d) variations could nullify the whole work. Similarly any historic survey of a long series of past records must take particular account of any variations of type (b). The second classification is the more relevant to the study of the variations themselves and to their detection and possible measurement. The study of changes in vessel and gear is, in the main, not a sampling problem but a question of the proper measurement of fishing power and fishing effort, and therefore outside the scope of this manual. More directly concerned with sampling techniques is the problem of the distribution of fishing power and fishing effort. This can be divided into distributions in time and space.

The shortest time scale over which changes are important is the day. For instance, trawl catches during daylight and darkness may differ quite considerably, but still the catch per hour during daylight will be proportional to the fish abundance, as also will the catch per hour during darkness, though with a different constant of proportionality. The catch per hour based on a small number of trawl hauls would therefore not provide a good index of abundance unless it was also specified what proportion of hauls were made in daylight and in darkness. Commercial trawling will often be carried out more or less continuously, so that the proportion of the total amount of fishing made in the darkness and in daylight will be the same from year to year. Diurnal variation is therefore only important in the analysis of commercial catches if there is any change in the daily habits of the fishermen — for instance, if night catches are normally poor they may cease to fish at all during the night at times when the general abundance of fish is very low.

Similar considerations may be applied to other short-term variations — for example, short-term differences in catches per unit effort due to

differences in weather may be assumed to become small when considering the mean catch per unit effort over, say, a year (though there may well be appreciable differences in the average weather conditions between short seasons of, say, a few weeks).

Seasonal fluctuations might also be neglected for the same reasons but there is more scope for fishermen to change their seasonal fishing pattern than their practice over a day — thus when fish are not abundant fishing for a given species may be carried out only at the peak of the season, when catch per unit effort is highest, but when fish are abundant fishing for this species might go on for most of the year. The net effect, of course, is to reduce the variation in the apparent catch per unit effort. This possible error can be reduced by suitable stratification. Instead of using as an index of abundance the annual catch per unit effort calculated as the total year's catch divided by the total year's effort, the year can be divided into periods, say months, each of which is, as usual, sampled separately. Then, there will be twelve independent indexes of abundance, each calculated as the month's catch divided by the month's effort. Any one of these could be used as an index of abundance, or a single mean calculated to give the index for the year. This might be the simple, un-weighted mean, or more weight could be given to the main fishing seasons. These weights must, of course, be the same for each year, so that it would be wrong to choose the weights as proportional to, say, the amount of fishing which would vary from year to year, but they could be chosen as proportional to the average amount of fishing in each month over some fixed period of years.

Example 4.3.1.1

Monthly catches of *Bagrus* spp. from Lake Menzala, Egypt, during the two years 1956/57 and 1957/58, and the corresponding fishing efforts were as follows:

Month	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May
1956/57 Catch (tons)	21	6	15	132	210	57	34	5	9	8	14	15
Effort	12	14	20	21	22	14	11	11	8	7	7	6
1957/58 Catch (tons)	9	3	15	210	288	20	32	4	3	2	3	10
Effort	6	7	25	42	36	10	8	7	3	2	2	5

Calculate the catch per unit effort in each month; calculate an index of abundance for each year (a) as the simple arithmetic mean of the monthly catch per unit efforts; (b) giving weights to each month of 6, 7, 15, 20,

19, 8, 6, 6, 4, 3, 3, 3⁻ respectively (roughly proportional to the average fishing). Compare these with the ratio of total year's catch to total effort. Compare the abundance of *Bagrus* in the two years (a) from any of the indexes above, based on stratified sampling; (b) as catch per unit effort in each year taken as a whole.

There is no reason for the time periods to be equal. In the example above, strata each of one month were used, as these were the basic periods used in collecting the data, but it might be better to group some months together in the seasons of poor fishing so as to have more or less equal amounts of fishing in each division. As usual the most important criterion in grouping is that within any one division the quantity being sampled (in this case catch per unit effort) is as uniform as possible. Thus it would certainly be correct to group data for February and March, and for April and May, together, while other groupings, e.g. July and August, are also possible. Conversely it may be better to divide the months of September or October into two fortnightly periods.

The example also demonstrates that the catch per unit effort in a single month can provide a reasonable index for the abundance over the year — that is, the changes in the catch per unit effort in, say, August of different years are proportional to the changes in the stock. Therefore, while it will in general be obviously better to base an index of abundance on catches over the whole year, it is quite possible to use data for only part of the year, either because little fishing is done at other times, or because in the rest of the year the catch per unit effort is not likely to be reliable (the fishermen are perhaps fishing then mainly for some other species).

The technique of stratified sampling is also useful in producing indexes of abundance undistorted by changes in the distribution of fishing in space. The whole area being fished is divided into subareas, and instead of taking as an index of abundance the ratio of total catch to total effort, the mean of the catches per unit effort in each subarea (weighted, if necessary) is used. Thus the main trawling grounds on the west coast of Greenland are a series of banks — Banana Bank, Danas Bank, Fyllas Bank, etc. A reasonable index of abundance for the west Greenland stock of cod would therefore be the mean of the catch per hour trawling on each bank. As the banks are of different sizes, a better index might be obtained by weighting the catches per unit effort by the area of the bank concerned (catch per unit effort measures density of fish, so multiplying by area should give abundance). The method clearly cannot be used directly unless data are available for each bank — i.e. in the usual terms a sample must be taken from every strata. This sets a lower limit to the size of area which can be used. In fact, it means that stratification by area can be used to study changes in what might be called fishing strategy, but not in fishing tactics. The success of the fishermen in moving to the particular Greenland bank where fishing is at that moment best — perhaps as a result of wireless information from other ships — might be regarded as the result of good strategy; good tactics is the ability to fish at the best spot on the bank

once he has arrived there — e.g. by direct detection of the fish “by” echo sounding, or by more precise navigation to keep exactly on the best spot for fishing — e.g. again by echo sounding, this time purely for determining depth, or by radar, Decca navigator, etc. Improvements in fishing tactics can be among the main contributions to a long-term increase in q , the ratio of catch per unit effort to fish density, and probably the ones that are most difficult to detect and measure. Further discussion of this problem is, however, outside the scope of this manual.

Stratified sampling by area to eliminate bias due to changes in fishing strategy is particularly useful where a fleet catches two or more species, whose distributions differ but overlap. Changes in the relative abundance of or market demand for the different species may cause quite different patterns of fishing effort distribution.

Example 4.3.1.2

The table below is an extreme simplification of English North Sea trawl data and represents the fishing effort and corresponding catches of plaice and haddock in two years, plaice being predominantly a southerly fish, and haddock northerly. The area has been divided into 16 subareas in each of which the data of catch and effort are recorded separately.

	1960				1961			
	5	6	6	3	16	17	13	14
Effort	50	48	60	24	208	238	195	168
Haddock	0	12	6	0	0	17	13	0
Plaice								
Effort	8	7	9	8	13	12	13	10
Haddock	40	49	54	48	130	132	91	80
Plaice	16	0	27	8	13	12	26	0
Effort	10	13	11	14	9	9	(8)	6
Haddock	40	65	33	56	45	63	(32)	48
Plaice	40	39	22	42	18	18	(8)	18
Effort	14	15	16	15	5	5	6	4
Haddock	28	0	16	15	10	5	6	4
Plaice	84	90	48	45	25	15	12	8

1. Calculate for each year the total catch of each species, and the total effort, and hence the ratio total catch/total effort.
2. Draw up a chart for each year showing the catch per unit effort of each species in each subarea.

3. Hence calculate an overall density index for each species, i.e. the mean catch per unit effort. Compare the change in density between the two years as measured by the ratio total catch/total effort, and by the mean catch per unit effort.

Another type of stratification is sometimes possible in a fishery for more than one species, when there is sufficiently little mixing between the species for any one catch — e.g. of a single trawl haul or other operation — to be predominantly of one species, even though both are present in the general area. Landings from individual fishing operations can therefore be divided according to the species primarily sought.

Example 4.3.1.3

German trawlers fish at west Greenland for both cod and redfish. Their catches in tons and fishing efforts during 1958 and 1959 were as follows (data taken from the *Statistical bulletins* of the International Commission for the Northwest Atlantic Fisheries).

	Primary species	Days fished	Catch of cod	Catch of redfish
1958	Cod	1 337	26 247	1 754
	Redfish	385	1 277	9 457
	Mixed	199	2 386	1 969
	TOTAL	1 921	29 910	13 180
1959	Cod	645	12 336	1 087
	Redfish	690	2 705	15 683
	Mixed	169	2 372	2 062
	TOTAL	1 504	17 413	18 832

Estimate, from the catch per unit effort of cod by the trawlers fishing for cod, and of redfish by trawlers fishing for redfish, the changes (as percentages) in the densities of the stocks of cod and redfish between 1958 and 1959. Compare these with the changes in the catches per unit effort of cod and of redfish by all vessels taken together, and also with the changes in the catches per unit effort of cod by the redfish vessels, and of redfish by the cod vessels.

4.4 Composition of the stock

Commercial landings will always to some extent be biased samples of the whole: fish that are too small, or in too poor a condition to

be sold, as well as unwanted species, will be rejected from the catches. The catches themselves will be biased, not only though the obvious geometrical characteristics of the gear — e.g. escape of small fish through the meshes of a net — but also because the fishermen will prefer to fish in areas where fish of the most valuable or abundant size etc., are present. Thus British trawlers fishing in the North Sea have a mesh size of about 80 mm (i.e. a little above the legal minimum of 75 mm); this mesh will retain most plaice longer than 20 cm in length and virtually all those longer than 22 cm. The minimum legal landing size is 25 cm, so that we can hope to use the commercial trawler landings to give information on the sizes of plaice above, say 28 cm (as rejection by the fishermen of under-sized fish will not be at the minimum size limit precisely). Thus, for a particular ground the population (say numbers per square mile), and the catch and landings of each size of fish by a trawler from ten hours' fishing might be as follows:

Length (cm)	5-10	10-14	15-19	20-24	25-27	28-29	30-34	35-39	40-44	45 +
Numbers per square mile (A)	500	700	820	780	360	230	180	80	40	20
Numbers caught	—	10	120	360	180	115	90	40	20	10
Numbers landed (B)	—	—	—	10	150	115	90	40	20	10
B/A	0	0	0	0.01	0.42	0.5	0.5	0.5	0.5	0.5

The bottom row shows that the ratio of numbers landed to numbers per unit area is constant above 28 cm, so that the landings give an unbiased picture of the length composition of the stock above this size. The landings per unit effort are equal to the average numbers within a certain area — half a square mile in the example. The size of this area will not be known, which is why the catch data are used to give indexes of abundance, not abundance in absolute terms, though its order of magnitude can be gauged from the geometry of the gear used. Thus a trawl might catch most of the fish in an area equal to the width of the net (or the distance between otter boards) multiplied by the distance covered. Many fish may, however, escape over or around the net, and also, on the other hand, the trawl may be fishing on a density of fish higher than the average.

The landings in our example are only representative of the stock on the grounds being fished. The sizes of plaice, like most other fish, vary quite markedly from ground to ground, the smaller fish being most abundant on the shallower grounds along the coast, and the bigger fish in the deep water. The size composition of the fish on different grounds, again in terms of numbers per square mile, might therefore be something like:

Length (cm)	-10	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45 +
Shallow	500	700	820	780	590	180	80	40	20
Moderate	—	50	150	320	400	200	100	70	40
Deep	—	—	20	50	150	180	120	80	60

Obviously in the example the landings (from fishing on the shallow grounds) give a biased picture of the length distribution of the fish above 28 cm in the stock as a whole; for example, they greatly underestimate the number of the fish longer than 45 cm (a ninth of those between 30 and 34 cm, compared with a third in deep water). This bias will still occur, even if fishing is done in all zones, unless the amount of fishing is exactly in proportion to the area of each zone.

Example 4.4.0.1

Assuming the areas of the zones above are: shallow 4,000 square miles; moderate 8,000 square miles; deep 5,000 square miles; calculate the total number of each size group in the stock. If in ten hours' fishing a trawler catches a quantity of fish equal to half the average numbers per square mile, calculate the total numbers landed in each length group above 30 cm, if 100,000 hours' fishing were carried out, distributed as follows:

- (a) shallow 50,000 hours, moderate 45,000 hours, deep 5,000 hours;
- (b) shallow 10,000 hours, moderate 40,000 hours, deep 50,000 hours.

Compare the length distributions (as percentages) of fish over 30 cm, in the stock and in the landings.

Unbiased estimates, or at least estimates with the bias reduced as far as possible, can be obtained by suitable stratification according to the area fished. The usual principles of stratified sampling apply, except that there is not full control on the source of the samples. The fishermen will fish where they want to, and not where their catches will give the best information for the scientist, and even the sampling of the landings by the scientist may not be fully controlled. For instance, trawlers may arrive at port during the night, and their crews go home immediately. The fish are unloaded and set out for the auction very early in the morning and have to be sampled then, and it is not possible to interview the crew and find out where the ship has been fishing until later, after the sampling has been done. Thus it will often not be possible to apportion the sampling effort (either by the commercial fisheries sampling the stocks, or by sampling the commercial catches) between areas in the most effi-

cient manner. The departure from full efficiency may not be large because most catches, and therefore most samples, will tend to come from the areas where most fish are. Because there are probably less differences between different places in the sizes of fish than in the density of fish, and because fewer samples of size distribution are available, the divisions of the whole area for stratification will probably be rather larger than those used to estimate an index of the total abundance. Usually the regions used in studying the length composition will be formed by groups of two or more of the areas used in the analysis of catch and effort statistics, the choice of grouping as usual being to group together areas with similar length compositions, and to ensure that there are some samples from each stratum.

These stratifications by area of catch, though essential for estimating the composition of the stock, may also be conveniently used for estimating the catch. Thus the procedure suggested earlier, for landings with no sorting into size categories was:

1. Measure a sample from the landing of each of several ships.
2. Raise each sample to the total landing by the ship (i.e. multiply the numbers in each size group in the sample by a raising factor equal to the weight of the total ship's landing divided by the weight sampled).
3. Add together landings by all sampled ships.
4. Raise to total landings for the period.

The procedure would now be:

1. Measure a sample from the landing by each of several ships.
2. Raise each sample to the total landing of the ship (as before).

Then, for each stratification separately:

3. Add together landings from all sampled ships fishing in the particular subdivision.
4. Raise to total landings from the subdivision.

Then the total landings for the whole region are obtained by addition of the totals for the individual subdivision from (4). To estimate the composition of the population, proceed as follows, if the efforts corresponding to the landings in (4) from each subdivision are known:

5. Divide landings from the subdivision obtained in (4) by the effort in the subdivision, to give the catch per unit effort of each length group.
6. Multiply by the area of the subdivision (to convert from units of density to units of abundance).

7. Add together all subdivisions.

This gives numbers proportional to the overall abundance of each length group, but if desired:

8. Divide by the total area of all subdivisions. This produces numbers which are again in the same scale of catch per unit effort (e.g. catch per 100 hours' trawling) as (5) — in fact, they are the weighted means of the numbers in (5), the weighting factors being the areas of the different subdivisions.

Alternatively, if the effort corresponding to the total landings is not known, so that the catch per unit effort of each length group cannot be calculated directly, then the percentage length composition of the landings from each subdivision can be calculated. The percentage of any length group in the stock can then be estimated as the weighted mean of the percentage of this length group in the landings from each subdivision. The weighting factors must be the numbers of fish (or strictly the numbers of fish of a size that may be caught and landed) in each subdivision — i.e. the density in numbers, times the area of the subdivision. The density in each subdivision may be estimated from such data on catches per unit effort as are available.

4.4.1 FISHING BY MORE THAN ONE FLEET

If more than one set of vessels is fishing the same stock of fish (different types of gear, or vessels from different countries), then it may be possible to obtain separate estimates of the composition of the stock, which should be combined in some way to give a simple "best" estimate. Provided that the differences are not too marked, and are no more than might be expected from the sampling errors, then this can be treated as a simple statistical problem. The combination should be done within the regional stratification discussed in the previous paragraph, i.e. a single estimate of the composition of the stock within each subdivision is obtained from all available data, and these are then combined to give the estimate for the complete stock. Within each subdivision the estimates from the various sets of vessels should be combined by taking the weighted mean, using as weighting factors numbers inversely proportional to the variances of the different estimates. These variances will not usually be known very precisely, but will be nearly inversely proportional to the number of samples taken, or to the number of fish measured from the landings of each group of vessels. The weighting factors may be therefore taken as proportional to the number of samples or to the number of fish measured.

If it is possible to use a standard unit of effort, and of catch per unit effort, for all groups of vessels, then it is best to express the estimated composition of the landings of each, and hence the combined estimate of the composition of the stocks, in terms of catch per unit effort. Sup-

pose, for example, two groups of boats are fishing for anchovy in a certain area, both using the same type of seine net, so that the unit of catch per hour is the same for both groups. Ten samples were taken from the first group, from which it was estimated that 160 fish of 11 cm were caught per hour's fishing; from eight samples from the second group it was estimated that 250 fish of 11 cm were caught per hour's fishing; the combined estimate is therefore

$$\frac{1}{18} \times (10 \times 160 + 8 \times 250) = 200 \text{ fish per hour's fishing.}$$

Similarly the combined estimate for every other length group can be obtained, giving the whole length composition for that particular area. Where, as here, the same raising factors are used several times, the computational work can be reduced through eliminating the need for repeated division, by dividing the raising factors to make their sum unity, i.e. in this case $10 + 8 = 18$, so using raising factors equal to

$$\frac{10}{18} \text{ and } \frac{8}{18}, \text{ i.e. } 0.556 \text{ and } 0.444, \text{ and}$$

the estimated density of 11-cm fish is $0.556 \times 160 + 0.444 \times 250 = 200$. This is then also done for every other area and the results combined — most easily if all are in terms of the same catch per unit effort.

If no standard effort units can be used, then the length compositions estimated from the landings of each group of vessels will have to be expressed as percentages, and combined in that form.

Example 4.4.1.1

A stock of sardines is fished by two groups of vessels in each of two different areas. In a certain year the number of samples taken and the resulting estimates of the number of fish caught in millions were as follows:

Area	Fleet	Samples	Length (cm)										
			18	19	20	21	22	23	24	25	26	27	28
Northern	A	50	1	8	15	28	30	27	20	13	7	4	2
	B	100	1	12	31	55	60	54	43	25	12	7	3
Southern	A	25	—	1	3	12	14	21	18	7	6	5	2
	B	20	—	2	4	13	13	23	18	10	5	2	1

Calculate the percentage-length composition of the catches of each fleet in each area; hence estimate the percentage-length composition of the stock in each area.

If the southern area is twice as big as the northern area, but echo surveys show that fish traces (assumed to be sardines) are 1.2 times as frequent in the northern area, estimate the percentage-length composition of the whole stock (take weighting factors north:south of $1 \times 1.2:2 \times 1$).

When there are appreciable differences in composition between the catches by different groups of vessels fishing in the same area, then clearly one group at least is selective and is catching an unrepresentative sample of the stock. Sometimes the nature of the selection can be guessed; for instance, if fish are being caught by trawl and gill net, then a difference between the catches, with the gill net catching relatively fewer very small and very big fish would be in agreement with the expected selective action of the gill net. The composition of the stock would then be estimated from the catches of the presumably nonselective gear — in this example the trawl. If the selection can be measured reasonably accurately — as is possible for a fleet of gill nets if the mesh sizes are known — then the composition of the catches can be used to give an estimate of the composition of the stock, which can then be combined with the estimate from the landings by the other group of ships. In this latter step less weight should probably be given to the estimates from the selective gear than is indicated by the number of samples, because of the added uncertainty introduced by the selection factors.

Example 4.4.1.2

Herrings are caught in the southern North Sea by trawl and drift (gill) net. The length composition of the catches (in thousands) and the estimated proportion of each size retained by the drift net (relative to the maximum retention) were as follows:

Length (cm)	21	22	23	24	25	26	27	28	29	30
Trawl numbers caught	30	320	1 200	1 400	1 180	760	345	76	5	2
Drift numbers caught	10	136	603	740	525	304	105	18	2	1
Drift, percentage retained	60	75	90	100	95	80	65	50	40	30

Estimate the percentage-length composition of the stock, giving twice as much weight to the trawl estimates.

Even if a gear is not obviously selective it cannot be assumed that it is in fact nonselective. Though the meshes of the herring trawls in the example above are too small to let through any herring bigger than about

15 cm, the catches could still be unrepresentative of the stock, e.g. the proportion of large herring could be underestimated because they tend to swim higher in the water and thus escape over the top of the trawl.

4.4.2 AGE-LENGTH KEYS

Just as the age (or maturity, etc.) composition of the landings can be estimated by direct sampling, but is more effectively estimated by direct sampling for length, with the use of age-length (or maturity-length, etc.) keys based on relatively small samples, so may the age composition of the stock best be estimated by applying age-length keys to the estimated length composition. Because many of the selection processes by the fishing fleet are related directly to fish length, the use of the key enables their effect on age, etc. to be readily determined. Thus, for the data on North Sea cod used earlier we can give the following age-length key, based on samples of the landings in the third quarter of the year.

Length (cm)	Number sampled of fish of each age								Total	Total
	1	2	3	4	5	6	7	8	Sampled	Landed (thousands)
30-	12	36							48	160
40-	1	73	3						77	488
50-	1	54	6						61	394
60-		13	25						38	205
70-			27	7					34	139
80-			8	12	7	3			30	75
90-				10	9	5	3		28	42
100-					4	2	7	3	15	15
100-						3	4	3	10	2

The known selective properties of the gear, and the market demand, are such that no cod less than 30 cm are landed, and only a fraction of those under 40 cm which are caught are landed. Thus the landings can only give a reasonable representation of the stock for fish over 40 cm. The age-length key shows that the landings may therefore be representative of the stock of three-year old fish and older, but that the numbers of two-year old fish are slightly underestimated, while the one-year old fish, most of which are under 40 cm, are very poorly represented.

If the selection in terms of length is known in quantitative terms, then the key can be used to estimate the selection in terms of age.

Example 4.4.2.1

From the data given above estimate the number of fish of each age landed. If, of the fish that enter the trawl, only 40 percent of those between

At and on the 1st day of June 1966, the undersigned, being duly sworn, depose and say that the above is a true and correct copy of the report of the Fish Commission of the State of New York, dated June 1, 1966, and that the same is a true and correct copy of the report of the Fish Commission of the State of New York, dated June 1, 1966, and that the same is a true and correct copy of the report of the Fish Commission of the State of New York, dated June 1, 1966.